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**AN APPARATUS FOR ADAPTIVE RESOURCE ALLOCATION FOR  
MULTI-CHANNEL COMMUNICATION SYSTEM, AND A METHOD  
THEREOF**

5                    **CROSS REFERENCE TO RELATED APPLICATION**

This application claims priority to and the benefit of Korea Patent Application No. 2003-0098213 filed on December, 27, 2003 in the Korean Intellectual Property Office, the entire content of which is incorporated herein by reference.

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**BACKGROUND OF THE INVENTION**

**(a) Field of the Invention**

The present invention relates to a resource allocation processor and a method thereof. More specifically, the present invention relates to a processor for adaptive resource allocation for a multi-channel communication system and a method thereof.

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**(b) Description of the Related Art**

Recently, the increase of the importance of image and data transmissions has created a demand for high-speed data transmission. Frequency resources are relevantly lacking, however, and therefore effective frequency use is necessary.

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In a conventional orthogonal frequency division multiplexing (OFDM) system, a fixed modulating method is used or a modulating method is determined in consideration of average signal to noise ratios (SNR) for respective users. In addition, it is important to separately  
5 determine the modulating method because various SNRs are provided for respective subchannels in the OFDM system.

As a prior art, the "Ensemble Modem structure for imperfect transmission media" is disclosed in US. Patent Application No. 5,054,034, filed on October 1, 1991, wherein bits are differently allocated for the  
10 respective subchannels with reference to SNRs of the respective subchannels in a multi-carrier system, and therefore a maximum data transmission speed or a maximum performance gain is provided.

According to the U.S. Patent Application No. 5,054,034, a ratio between a SNR for each subchannel and a SNR gap is computed. At this  
15 time, the SNR gap is determined by an error correction coding method or a desired bit error probability, and it represents a difference between a practical SNR and a desirable SNR to be required when a predetermined number of bits is transmitted. A number of subchannels to be used,  $k$ , is initialized to be 1, a maximum number of bits to be transmitted is initialized  
20 to be 0, and the recursive process is started. For a present number  $k$ , a number of bits to be transmitted to the respective subchannels is then computed, and the greatest number of bits is calculated. The process is

repeatedly performed until  $k$  corresponds to a number of the subchannels,  $N$ , and a maximum value among the number of bit sums becomes a maximum number of bits. At this time, the number of bits is a final number of bits to be transmitted to the respective subchannels. A required power value is calculated by the final number of bits, the power is predetermined as a standard so as to establish a sum of the calculated values to be a desired value, and a subchannel allocation power is finally calculated. In this application, in order to adaptively allocate bits according to the SNRs for the respective subchannels in the OFDM method, the bits to be allocated to the subchannels are calculated increasing the number of usable subchannels with reference to SNR for each step, and therefore an optimal bit allocation is performed by using SNR in the OFDM method.

Also, in a paper entitled "Computationally Efficient Optimal Power Allocation Algorithms for Multi-carrier Communication Systems" by B. S. Krongold, disclosed in a journal, IEEE Trans. Commun, Vol. 1, pp. 23-27, 2000, a bisection method for solving modulating method determination and bit allocation problems is applied for the purpose of allocating with reference to SNR and determining a modulation method for each subchannel in the discrete multitone modulation (DMT) system. In the paper, when assuming that transmitter end is aware of channel information in the DMT system, the frequency resource is efficiently used by discriminating users according to the channel information in a

frequency band.

According to the paper, it is difficult to directly find an optimal solution for a nonlinear optimization problem having an integer type of variable, and therefore the solution for the nonlinear optimization problem is found when integer conditions on variables are eliminated, and a final integer solution is found by quantizing the given real number solution. At this time, an optimal solution for the problem has not yet been provided because it is very complicated to find the solution for the optimization problem, and the integer solution is found by quantizing the given real number solution.

In addition, in a paper entitled "Increase in Capacity of Multiuser OFDM System using Dynamic Subchannel Allocation" by W. Rhee and J. M. Cioffiis, disclosed in the journal Proceedings of IEEE VTC', 2000, pp. 1085-1089, a subchannel to be allocated to each user is determined with reference to channel information in a multiuser OFDM method, an allocation power is then determined in the subchannel and therefore a problem is formulated establishing power for each subchannel and each user as a variable in order to maximize a total capacity, and an intuitional method for solving the problem is disclosed.

According to the paper, performance is expected to be reduced because the power is correspondingly distributed when the capacity for each user and each subchannel is computed. Although the capacity is

maximized, the capacity is a real number value and an integer value is only used in a practically used modulation method. Accordingly, it is difficult to use the given value for a practical transmission.

A modulation method determination process is required to be performed for respective channels and time slots in order to adaptively allocate resources in the OFDM and a time division multiple access (TDMA). It is, however, difficult to practically realize in methods according to the prior art because it is very complex to perform the modulation method determination process.

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### **SUMMARY OF THE INVENTION**

The present invention provides an adaptive resource allocation processor for simply and efficiently performing modulation method determination for each subchannel of an OFDM system in the multi-channel communication system, and a method thereof.

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Additional features of the invention will be set forth in the description which follows, and in part will be apparent from the description, or may be learned by practice of the invention.

The present invention discloses an adaptive resource allocation method in the multi-channel communication system. In the method, a) a number of bits to be transmitted is allocated according to a subchannel quality, b) a minimum power for a total required transmission rate is

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determined, c) a channel gain for the subchannel is determined according to the allocated number of bits and power, and d) a modulation method for each subchannel is determined with reference to the channel gain. At this time, a Lagrange multiplier  $\lambda$  is analytically and experimentally estimated to allocate the number of bits.

In d) determining the modulation method for each subchannel, an adaptive convex search is repeatedly performed according to the average power and transmission rate, and a final modulation method is determined as one subchannel unit with reference to the convex search result.

At this time, a relation between the average power and the transmission rate is represented as  $P(R) = \sigma^2 \alpha^{-R}$  and  $R > 0$ ,  $P(R)$  denotes an average power-transmission rate function,  $\sigma^2$  denotes a variance of radio wave signals, and  $\alpha$  is greater than 1.

In performing the convex search, a) supremum  $\lambda_l$  and infimum  $\lambda_u$  of object transmission rates are respectively initialized to be 0 and  $\infty$ , b) a initial Lagrange multiplier estimate  $\lambda$  corresponding to the object transmission rate  $R_l$  is experimentally selected, c) a transmission rate non-constraint problem is solved until a Lagrange multiplier  $\lambda$  corresponding to the object transmission rate  $R_l$  is found, d) a lowest transmission rate  $R_l$  and a highest transmission rate  $R_h$  are searched, and e) the transmission rate non-constraint problem is solved.

The present invention also discloses an adaptive resource

allocation processor in a multi-channel communication system. The adaptive resource allocation processor includes a channel estimator for estimating a channel quality, an adaptive subchannel allocator for determining a channel gain for a subchannel with reference to the estimated channel value and allocating bits and power for the subchannel with reference to the channel gain, and an adaptive bit loader for outputting a bit table and a power table according to the allocated bits and power. The adaptive resource allocation processor further includes a symbol mapper and a symbol demapper for respectively mapping and demapping bits and power of symbols according to the bit table and the power table.

The present invention provides a high speed algorithm for determining a modulation method for each subchannel to be used by using a channel response for the subchannel as a resource allocation method in the OFDM system, and therefore a system is easily realized by reducing the complexity comparing to the prior art and frequency usage efficiency is greatly increased when the adaptive modulation is applied in an outdoor data communication system operating in the OFDM method.

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### **BRIEF DESCRIPTION OF THE DRAWINGS**

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate an embodiment of the

invention, and, together with the description, serve to explain the principles of the invention.

FIG. 1 shows a block diagram for representing a configuration of an adaptive resource allocation processor in an OFDM communication system according to an exemplary embodiment of the present invention.

FIG. 2 shows a graph for representing channel response characteristics for 128 subchannels in an OFDM communication system according to the exemplary embodiment of the present invention.

FIG. 3 shows a graph for representing a bit allocation result when a method according to the present invention is used in the subchannel response curve shown in FIG. 2 in order to describe an adaptive resource allocation method in the OFDM communication system according to the exemplary embodiment of the present invention.

FIG. 4 shows a graph for representing a relation between Lagrange multipliers and conventional transmission rates in order to describe an adaptive resource allocation algorithm according to the exemplary embodiment of the present invention.

FIG. 5 shows a graph for representing an adaptive convex search algorithm process for searching an optimal solution  $\lambda^*$  for a given object transmission rate  $R_t$  in the exemplary embodiment of the present invention.

FIG. 6 shows a graph for representing a comparison between average channel capacity and system efficiency for each OFDM symbol in

the OFDM communication system according to the exemplary embodiment of the present invention.

FIG. 7 shows a table for representing a comparison of performance between an algorithm according to the exemplary embodiment of the present invention and the conventional algorithm.

### **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

In the following detailed description, only the preferred embodiment of the invention has been shown and described, simply by way of illustration of the best mode contemplated by the inventor(s) of carrying out the invention. As will be realized, the invention is capable of modification in various obvious respects, all without departing from the invention. Accordingly, the drawings and description are to be regarded as illustrative in nature, and not restrictive. To clarify the present invention, parts which are not described in the specification are omitted, and parts for which similar descriptions are provided have the same reference numerals.

The respective subchannels encounter frequency non-selective fading without interference between each other due to an inverse fast Fourier transform (IFFT) of a transmitter end and a fast Fourier transform of a receiver end in the like manner of OFDM or OFDMA. In the OFDM system, an appropriate modulation method is allocated to the subchannel

according to a desired data transmission speed regardless of a channel gain of the subchannel.

In the exemplary embodiment of the present invention, a modulation method determination device for the subchannel is provided in a front end of IFFT, and it is established to use respective modulation methods according to the channel gains. Information on the determined modulation method is required to be transmitted to the receiver end by using an additional control channel, and the modulation method for each subchannel is found by the information on the modulation method and used for a demodulation in the receiver end.

In the exemplary embodiment of the present invention, the channel response is required to be found so as to provide a high speed search algorithm determining the modulation method for each subchannel to be used by using the channel response on the subchannel as a method for the resource allocation in the OFDM system, and the channel response is able to be found by estimating the channel in a time division duplex (TDD) system in which uplink and downlink channel responses are assumed to correspond to each other. The modulation/demodulation method information determined by the method according to the exemplary embodiment of the present invention is required to be transmitted to the receiver end through an additional channel because the estimated channel response is required to be transmitted through a control channel

in a frequency division duplex (FDD) system.

The adaptive resource allocation method of the communication system for efficiently performing the modulation method determination of the subchannel a) determines the channel gain of the subchannel and b)  
5 determines the modulation method of each subchannel, which will be described with reference to the following figures.

FIG. 1 shows a block diagram for representing a configuration of an adaptive resource allocation processor in an OFDM communication system according to the exemplary embodiment to the present invention.  
10 As shown in FIG. 1, an adaptive resource allocation processor 110 according to the exemplary embodiment of the present invention includes an adaptive subchannel allocator 111, an adaptive bit loader 112, and a channel estimator/noise generator 113.

A noise variable (Noise\_Var) generated from the channel  
15 estimator/noise generator 113 is input to the adaptive subchannel allocator 111, the adaptive bit loader 112, and a radio channel 120, and the noise variable is input to a symbol mapper 130 and a symbol demapper 140 for respectively mapping and demapping bits and power of respective symbols according to a bit table and a power table output from  
20 the adaptive bit loader 112.

A method for the adaptive resource allocation in the OFDM communication system will be described with reference to the

configuration shown in FIG. 1.

A value of the channel gain of each subchannel is represented as  $|H|_n^2$  ( $n=1, \dots, N$ ) when a number of the subchannels is  $N$ , and a number of bits and power allocated to each subchannel are given as Equation 1 when the number of bits and power are respectively represented as  $C_n$  and  $P_n$ .

【Equation 1】

$$P_n = \frac{f(c_n)}{|H_n|^2}$$

where  $f(c_n)$  denotes a power for receiving the bit  $C_n$ .

FIG. 2 shows a graph for representing channel response characteristics corresponding to 128 subchannels in an OFDM communication system according to the exemplary embodiment to the present invention, and the graph shows response characteristics of the randomly generated subchannel.

FIG. 3 shows a graph for representing a bit allocation result caused when a method according to the present invention is used in the subchannel response curve shown in FIG. 2 in order to describe the adaptive resource allocation method in an OFDM communication system according to the exemplary embodiment to the present invention, and the graph shows a transmission number of bits for each subchannel. As shown in FIG. 3, more bits are transmitted to one subchannel when the

channel quality is good, and fewer bits are transmitted when the gain of the subchannel is bad.

For the purpose of solving the optimization problem, the transmit number of bits for the adaptive modulation in the OFDM system is allocated by using Equation 1, and the total power  $P_T$  is minimized by using Equations 2 and 3.

【Equation 2】

$$\min_{c_n} P_T = \min_{c_n} \sum \frac{f(c_n)}{|H_n|^2} \text{ for } c_n \in \tilde{C}$$

【Equation 3】

$$\text{Subject to } R = \sum_{n=1}^N c_n$$

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where  $R$  denotes an object data amount, and  $R(c_n)$  and  $P(c_n)$  respectively denote a transmission rate function and a power function for mapping a modulation of a signal  $\vec{x}$  to  $C_n$  in order to find an optimal solution for the problem. The transmission rate constraint power optimization adaptive modulation is a method for allocating respective subchannel modulations in order to use a minimum power for the required total transmission rates. That is, a vector of modulation for an input signal is given as Equation 4.

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【Equation 4】

$$\tilde{C} = (c_1, c_2, \dots, c_N)$$

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In this case, the transmission rate constraint for the total object number of bits  $R_t$  is given as Equation 5.

【Equation 5】

$$R(\vec{C}) = \sum_{i=1}^N R_i(c_i) \leq R_t$$

5 The power for transmitting the total object number of bits is given as Equation 6.

【Equation 6】

$$P(\vec{C}) = \sum_{i=1}^N P_i(c_i)$$

10 A vector  $\vec{C}$  for minimizing the power is found with reference to the above equations.

At this time, the transmission rate constraint problem of Equations 4 to 6 may be simplified into a non-constraint problem by using a Lagrange multiplier  $\lambda$ . The simplifying process is based on an integer bit allocation process, and is given as in the following equations.

15 The Lagrange multiplier  $\lambda$  is estimated in an experimental way for the purpose of applying the Lagrange multiplier  $\lambda$  to a practical problem for the bit allocation. In addition, the non-constraint problem may be embodied by Equation 7 in order to disclose a further organized method for finding the Lagrange multiplier  $\lambda$ .

20 【Equation 7】

$$\min_{\{c_n\}} \{P(\bar{C}) - \lambda R(\bar{C})\} = \min_{\{c_n\}} \sum_{n=1}^N \{P_n(c_n) - \lambda R_n(c_n)\}$$

An optimal solution for minimizing a total sum by minimizing each item is given by Equation 7, and exclusively finding a solution for each item is shown as Equation 8.

5                   【Equation 8】

$$\min_{c_n} \{P_n(c_n) - \lambda R_n(c_n)\}, \text{ for } n = 1, \dots, N$$

When a transmission rate for a predetermined rate or a highest transmission rate for a plurality of solutions is less than the object transmission rate  $R_t$ , a lesser Lagrange multiplier  $\lambda$  is selected for the purpose of having a solution representing a higher transmission rate in a next step. That is, when the predetermined solution is greater than the object transmission rate  $R_t$ , a higher Lagrange multiplier  $\lambda$  is selected for the purpose of having a solution representing a lesser transmission rate in the next step. This process is repeatedly performed until a Lagrange multiplier  $\lambda$  corresponding to the object transmission rate  $R_t$  is found.

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FIG. 4 shows a diagram for representing a relation between the Lagrange multiplier and the conventional transmission rate for the purpose of describing an adaptive resource allocation algorithm according to the exemplary embodiment of the present invention.

20                   A relation between an average power and the transmission rate for the given channel response and a modulator is given as Equation 9.

That is, an average power-transmission rate function  $P(R)$  is given as Equation 9.

【Equation 9】

$$P(R) = \sigma^2 \alpha^{-R}, \quad R \geq 0$$

5                where  $\sigma^2$  denotes a variance for radio wave signals, and at this time,  $\alpha$  is greater than 1.

A quick astringency and an initial value selection are keys to using the repetitive method for solving the non-constraint problem of Equation 7. As shown in FIG. 5,  $\lambda_l$  and  $\lambda_u$  for satisfying a relation of  
10                 $R(\lambda_u) \leq R_t \leq R(\lambda_l)$  may be selected in order to solve the problem.

FIG. 5 shows a diagram for representing an adaptive convex search algorithm process for searching an optimal solution  $\lambda^*$  for the object transmission rate  $R_t$  in the exemplary embodiment of the present invention.

15                As shown in FIG. 5, the adaptive convex search algorithm is provided in order to search the optimal solution  $\lambda^*$  for the object transmission rate  $R_t$ . Equation 10 is derived from the Equations 7 to 9.

【Equation 10】

$$\lambda = -\frac{\partial P(R)}{\partial R} = \alpha^{-R} \sigma^2 \ln \alpha$$

20                 $\lambda_l$  and  $\lambda_u$  are estimated by Equation 10, and a relation between them is also estimated by Equation 10.

【Equation 11】

$$\lambda_u = \alpha^{-R(\lambda_u)} \sigma^2 \ln \alpha$$

【Equation 12】

$$\lambda_l = \alpha^{-R(\lambda_l)} \sigma^2 \ln \alpha$$

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【Equation 13】

$$\frac{\lambda_u}{\lambda_l} = \alpha^{R(\lambda_l) - R(\lambda_u)}$$

Accordingly, an optimal  $\lambda^*$  corresponding to the object transmission rate  $R_l$  is derived from Equations 10, 11, 12, and 13.

【Equation 14】

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$$\begin{aligned} \lambda^*(R_l) &= \alpha^{-R_l} \sigma^2 \ln \alpha \\ &= \lambda_l \alpha^{R(\lambda_l) - R_l} \sigma^2 \ln \alpha \\ &= \lambda_l \left( \frac{\lambda_u}{\lambda_l} \right)^{\left( \frac{R(\lambda_l) - R_l}{R(\lambda_l) - R(\lambda_u)} \right)} \end{aligned}$$

Similarly, a following optimal  $\lambda^*$  corresponding to the object transmission rate  $R_l$  is also derived from Equations 10, 11, 12, and 13.

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【Equation 15】

$$\lambda^*(R_l) = \lambda_u \left( \frac{\lambda_l}{\lambda_u} \right)^{\left( \frac{R_l - R(\lambda_u)}{R(\lambda_l) - R(\lambda_u)} \right)}$$

The adaptive convex research algorithm for searching the optimal solution  $\lambda^*$  for the given object transmission rate  $R_t$  is performed as in the following processes by using Equations 14 and 15.

5 A Lagrange multiplier infimum  $\lambda_l$  and a Lagrange Multiplier supremum  $\lambda_u$  are selected to be respectively 0 and  $\infty$  as an initialization for minimizing a total symbol power for the object transmission rate  $R_t$ .

a) An initial Lagrange multiplier estimate  $\lambda$  for the object transmission rate  $R_t$  is selected in an experimental way.

10 b) The non-constraint problem Equation 7 is solved as follows:  
the lowest transmission rate  $R_l$  (number of bits) and a highest transmission rate  $R_h$  are found when the Lagrange multiplier  $\lambda$  is a singular value; and

one transmission rate satisfying a relation of  $R_l=R_h=R(\lambda)$  is found when the Lagrange multiplier  $\lambda$  is a non-singular value.

15 c)  $R_l$  and  $R_h$  are searched as follows:

$\lambda$  becomes  $\lambda^*$  when a relation of  $R_l \leq R_t \leq R_h$  is given, and at this time, the optimal solution is found, and therefore the process is finished;

a transmission rate  $R_H(>R_h)$  in which a power reduction rate is maximized comparing to the transmission rate increase at  $R_h$  is found  
20 when a relation of  $R_h < R_t$  is given. the supremum  $\lambda_u$  is updated with an inclination between  $R_h$  and  $R_H$ . At this time,  $R_H$  is given by searching available modulation methods having transmission rates greater than  $R_h$ .

At this time,  $\lambda_u$  becomes  $\lambda^*$  when a relation of  $R_h \leq R_t \leq R_H$  is given, the optimal solution is found, and therefore the process is finished. If  $\lambda_l$  is 0, the Lagrange multiplier  $\lambda$  for a next process is estimated in an experimental way. When  $\lambda_l$  is not 0, the Lagrange multiplier  $\lambda$  for a next process is estimated by Equation 14 or Equation 15 ; b) is performed again;

a transmission rate  $R_L (< R_t)$  in which a power reduction rate is maximized compared to the transmission rate increase at  $R_t$  is found when a relation of  $R_t > R_t$  is given.  $\lambda_l$  is updated with an inclination between  $R_t$  and  $R_L$ .  $R_L$  is obtained by searching available modulation methods having transmission rates less than  $R_t$ . At this time,  $\lambda_l$  becomes  $\lambda^*$  when a relation of  $R_L \leq R_t \leq R_t$  is given, and the optimal solution is found, and therefore the process is finished. If  $\lambda_h$  is  $\infty$ , the Lagrange multiplier  $\lambda$  for a next process is estimated in an experimental way. When  $\lambda_h$  is not  $\infty$ , the Lagrange multiplier  $\lambda$  for a next process is estimated by Equation 14 or Equation 15 ; and

b) is performed again.

The described adaptive convex search algorithm according to the present invention is further simply computed while showing a performance of the optimal solution. A final modulation method is determined by applying a modulation method determination used in the OFDM system as a subchannel unit through the above process. A performance is shown as

FIG. 6 when the algorithm according to the present invention is used in a wireless LAN system based on the OFDM.

FIG. 6 shows a graph for comparing average channel capacitance and system efficiency for each OFDM symbol in the OFDM communication system according to the exemplary embodiment of the present invention, wherein three modulation methods (QPSK (Quaternary Phase Shift Keying), 16QAM (Quadrature Amplitude Modulation), and 64 QAM) are applied for 128 subchannels, a data transmission rate is 258.3 Msps, and a required BER is  $10^{-5}$ . The channel is a Rayleigh fading channel, an exponent functional power reduction is assumed, and a maximum delay spread is assumed to be 70ns. At this time, a result of simulation tests is a value obtained by an average of 100 times repeated tests.

FIG. 7 shows a table for comparing performances between the algorithm according to the present invention and the conventional algorithms. Average repeat numbers for the optimal bit allocation in the conventional algorithms and the algorithm according to the present invention are compared to each other in the table, and the table shows that the complexity is simply realized according to the present invention.

While this invention has been described in connection with what is presently considered to be the most practical and preferred embodiment, it is to be understood that the invention is not limited to the disclosed

embodiments, but, on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.

According to the present invention, the complexity is significantly  
5 reduced compared to the conventional system, and is simply realized when the adaptive modulation method is applied in an indoor data communication system operating in the OFDM method.

According to the present invention, a considerable usage power gain is provided compared to the system using the conventional fixed  
10 modulation method, and frequency usage efficiency is further increased.